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Dr. Dimitri N. Mavris

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Georgia Institute of Technology
School of Aerospace Engineer
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14. ABSTRACT

The overall objective of this research is to create and test innovative design and decision-making methods with naval system affordability as the focus. The research objective is thus aligned to ONR's, as well as the Department of Navy's (DoN), goal of improving naval operational effectiveness through addressing affordability/Total Ownership Cost (TOC), uncertainty, and risk in Science and Technology (S&T). In this work, the Aerospace Systems Design Laboratory (ASDL) is conducting five, inter-related basic research tasks for ONR's consideration. Over the past several years, funding under ONR has allowed ASDL researchers to create several new breakthroughs in understanding affordability and quantifying affordability attributes in relation to new technologies, variable mission requirements, numerous uncertainty factors, and operational considerations. Each task now being conducted builds upon and extends successful research results achieved by ASDL under ONR's sponsorship during the last 4 years as well as key lessons learned from recent technology transitions successes. The primary areas of investigation include the study of "evolutionary" vs. "revolutionary" technology dynamics and means to compute these dynamics, an exploration of a new approach for the technology development process, the application of control theory analogy to design robust, affordable systems, and the examination of game theory for technology selection. The underlying foundation for all of the work is the use of advanced probabilistic tools and techniques to analyze and predict affordability measures and technology development dynamics. If successful, this research will assist the Navy's core S&T mission of designing and developing affordable (meaning capable AND cost effective) systems.

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(in support of accompanying presentation charts)
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Task1: Understanding Evolutionary/Revolutionary Technology Transitions

Objective

There is a growing need in the Navy for the ability to discern between whether to invest in "evolutionary" or "disruptive" solutions. ***The ultimate motivation of this research task is to understand the nature of technology transition dynamics, from an engineering and S&T investment point of view in order to maximize the probability of success of S&T investments.***

Approach

Study rise/run analysis and techniques for linking business strategy and technology dynamics.

Progress

Result: An approach has been created and is reported in the technical paper: *AIAA 2002-0515 An Approach for the Intelligent Assessment of Future Technology Portfolios*
Result: A synopsis of the key findings on the tools are listed below:

- *Text Mining (brief description follows)*
- *Innovation Indicators*
- *Innovation Flow Mapping*
- *Competitive Technological Intelligence*
- *Technology Roadmapping*

Text mining should not be confused with the better known Internet search engine tools or database management capabilities. Analogous to data mining, which extracts useful information from any type of data with large quantities, text mining is a procedure applied to large volumes of free unstructured text. After a traditional search for documents is completed, such as in format of full text, abstracts, or indexed terms, text mining explores the complex relationship among documents.

Science & Technology (S&T) text mining is the application of text mining to highly detailed technical material. There are three major components of S&T text mining:

(1) Information Retrieval, the foundational step of text mining. It is the extraction of relevant records from the source technical literatures or text databases for further processing.
(2) Information Processing, the extraction of patterns from the retrieved data obtained in the previous step. According to Kostoff, it has three components: bibliometrics, computational linguistics and clustering techniques. This step typically provides ordering, classification and quantification to the formerly unstructured material.
(3) Information Integration. It is the combination of the information processing computer output with the human cognitive processes.

Task 2: Advanced TIES with Investment Analysis

Objective

Seek new, improved technology development processes that work complimentary with the Technology Identification Evaluation and Selection (TIES) process that ASDL has developed for ONR. A technology development process is "a process of testing and analysis that progressively *reduces the programmatic risk* of selecting that technology for an application and *increases the readiness* of that technology for use in a mission."

Approach

Several thrusts comprise the approach. First, current methods, even those based upon TIES, do not account for technology investment cost. Thus, the addition of a means for calculating investment cost, which is under investigation, will allow for more accurate technology tradeoffs. Second, a direct treatment of the maturation time of technologies needs to be addressed. By accounting for time, designers will have better knowledge of when a technology will be ready. Third, the use of methods to propagate technology uncertainty are proposed to update performance values as technologies are developed, then the performance estimates used in TIES will be more representative of the actual technology capability.

Progress

For this task ASDL has researched background information on how technologies develop, and what techniques are useful for modeling technology development. The following techniques were identified as being useful for quantifying the cost, performance, and schedule for technology development:

- The TRL scheme of quantifying technology development level
- Activity network diagrams, used to probabilistically calculate investment cost and time (modeled through MATLAB's Simulink environment)
- Bayesian statistics, for use in quantifying the change in performance uncertainty over a development project

Other current progress includes:

- Further refinement of the Simulink activity network environment to include performance values and Bayesian calculations
- Demonstration of the techniques identified through applying them to a realistic development project for a single technology
- Demonstration of how these techniques benefit the TIES methodology development project

Task 3: Networked Systems and System Dynamics

Objective

Explore and assess the 'much touted' fields of *system dynamics* and *agent-based modeling*, in an attempt to understand the following research question: *are such methods useful in augmenting probabilistic design methods, especially for complex system-of-systems, important to the Navy?*

Approach

The complexity of individual systems, and the increasing cases of large numbers of interconnected systems, demands a search for modeling approaches that can capture these complexities and make use of them in a design for affordability setting. The approach for this task is to first, review the literature in fertile fields such as system dynamics and agent-based modeling. The second step involves classifying potential useful theories and algorithms in terms of complex problems important to the Navy (such as the design of Electric

Ships, and especially the power distribution system). Finally, employment of the most promising approaches in conjunction with ASDL's probabilistic design process will be executed to answer the research question posed.

Progress

The literature review has commenced and been fruitful. It is rich, but 'firm' principles of application are elusive. One critical motto that emerges is: Don't "model the system", but instead "solve the problem". System dynamics is a mature field of knowledge in which causal loop analysis and aggregated stocks and flows are employed to simulate the dynamics of a complex system or "system-of-systems". System Dynamics begins with the recognition that all models are wrong, but some can be particularly useful. By modeling the process of interest with System Dynamics, complex systems that are beyond the understanding of our mental models can be better understood. Agent-based modeling is characterized by the modeling of individual behavior instead of aggregated system behavior. The system behavior is said to "emerge" from the simulated agent interaction. An exploratory implementation is underway on a NASA project, including a comparison of system dynamics and agent-based approaches.

Task 4: Control Systems Analogy for System Design

Objective

The TIES process, and other available approaches for S&T resource allocation, produce essentially "snapshots" in time only. However; true robustness is time-variant and thus the main research target is: Decision making algorithm under time-varying uncertainty, in essence to control the design evolution itself, especially at the conceptual or pre-conceptual stages.

Approach

A theoretical analogy is explored consisting of the robust control model. The robust control model provides avenues to handle both the time-varying and uncertainty management characteristics. However, its adaptation to complex system design is untried. The initial steps of the approach, then, are concerned with mapping and defining the problem statement to see if a direct re-cast of the standard form is applicable. Following this, test problems related to design/affordability will be created and simulated solutions will be sought to try to find the weaknesses (and strengths) in the proposed concept.

Progress

Theoretical studies indicate that there are some differences; there are some nuances; there are many challenges remaining; *they all need to be explored further. An initial application problem has been attempted* on the design of a notional, multi-role, carrier-based aircraft, similar in several respects to the development of the U.S. Navy's F/A-18E/F. In this application example, the goal is to understand the implementation issues of the feedback system formulation and the avenues for examining uncertainty sensitivity. Initial findings indicate that the robust control analogy is worth pursuit, but does require some significant modifications to the algorithms normally employed.

Task 5: Game Theory for Product Architecture/Requirements Co-evolution

Objective

The objective is to use game theoretic ideas as a basis for *analytical* exploration of decisions (both engineering and business) and to find ways of mimicking nature's natural selection processes and using them to find global "optimal" business decisions.

Approach

In a mathematical sense, a game is a model of a competitive situation. It Identifies interested parties and stipulates rules for competition. *Game Theory* is a set of mathematical methods for analyzing these theoretical game models and selecting an *optimal strategy* for interested parties. Game Theory has the potential to provide a mathematical basis for the following tasks:

- Enumerating decisions available
- Evaluating options or "moves"
- Ruling out moves that do not make strategic sense
- Determining when partnerships are/are not optimal strategies

Progress

The simple game model presented shows that *even simple games can be useful* in helping to understanding the viability of reaching a new engine configuration in terms of resources and competition. The idea of *competitive adaptation* was introduced and used to solve a simple game model. The investigated method is able to find expected equilibrium points for simple scenarios. This game could easily be expanded to include more engine parameters, resources, and competitive assessments. Possible applications to systems design and business decision-making described further in the ISABE Paper 2001-1169.

Option 1: Affordability Methods for Electric Ship

Objective

The objective of the proposed research is to apply and develop/modify affordability methods to systematically assess the net impact of specific electric technologies at the ship level in terms of performance and affordability. A secondary objective is the visualization of affordable trades. Ideally, such results would be best used in a "electric ship mini-conference" where the key investigators and ONR personnel involved in electric ship could gather and interactively discuss the trades. This is possible since a hallmark of ASDL's affordability tools have been the ability for rapid, interactive trade-space visualization. In order to accomplish these objectives, ASDL has partnered with Syntek, who will supply the naval synthesis and sizing expertise as well as the ship synthesis modeling tool, Parametric Analysis of Ship Systems (PASS).

Approach

The approach taken for this task is the Technology Identification, Evaluation, and Selection (TIES) process developed under ONR grant (N00014-97-1-0783). The TIES environment is used to prove its usefulness and validity by implementing a series of proposed electric ship technologies that ONR is considering for use on a ship baseline. The ship baseline, a DDG051 class, was determined by as well as provided by Syntek.

Progress

The progress during the first year of this task actually accomplished the planned tasks for the second year. The details of what has been done are listed below.

- Decompose technology study into main generation, auxiliary generation, ship service distribution, and propulsion
- Adopt the same ship level responses from above
- Establish electric ship technologies
  - Identify technology impact factors within the ship synthesis program to simulate all technologies for all subsystems listed above
  - Organize technology impact factors in a technology impact matrix (TIM)

  - Determine and organize the compatibility of technologies in a technology compatibility matrix (TCM)
- Conduct design of experiment using the technology impact factors
  - Set up PASS input files according to design of experiments
  - Execute all PASS simulations
  - Record responses for each PASS simulation
- Perform multivariate regression to create technology space response surface equation

One final note on the progress of this task. One of ONR's goals for exercising this option was to promote technology transfer of its basic research methods. Through this option, ASDL is in the process of negotiating a Memorandum of Agreement/Teaming Agreement with both Syntek and Band Lavis & Associates (developers of PASS). Such an agreement will no doubt promote further technology transfer to the naval/marine design community.